INDIRECT CONSTRAINTS ON R-PARITY VIOLATING STOP COUPLINGS

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It was recently claimed that single stop production at the Tevatron, occurring via R-parity (and baryon number) violating couplings, could lead to observable signals. In this talk I present some results of a work in progress [1], showing that rare B^+ decays and K^0–$\bar{K}^0$ mixing strongly constrain such a possibility.

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In the Minimal Supersymmetric Standard Model (MSSM) it is assumed that R-parity (R_p) is conserved [2]. While the particles of the Standard Model are even under R_p, their supersymmetric partners are odd, thus the latter can only be produced in pairs and they always decay into final states involving an odd number of supersymmetric particles. Although it considerably simplifies the structure of the MSSM, the conservation of R-parity has no firm theoretical justification (for a review and references on versions of the MSSM with broken R-parity, see e.g. ref. [3]). The most general R_p-violating superpotential that can be written with the MSSM superfields contains both lepton number and baryon number violating terms. Their simultaneous presence is in fact strongly limited, since it would induce fast proton decay. However, it is possible to allow for the presence of baryon number violating couplings only [4], coming from the superpotential

$$\mathcal{W}_{\not B} = \lambda''_{ijk}\, \epsilon^{\alpha\beta\gamma}\, U^c_{i\alpha}\, D^c_{j\beta}\, D^c_{k\gamma}\ , \tag{1}$$

where U^c and D^c (c denotes charge conjugation) are the chiral superfields associated with SU(2)-singlet antiquarks, in a basis where the quark masses are diagonal, $i, j, k = 1, 2, 3$ are flavor indices and $\alpha, \beta, \gamma = 1, 2, 3$ are color indices. The color structure of $\mathcal{W}_{\not B}$ implies that the λ''_{ijk} are antisymmetric in the last two indices, limiting the number of independent couplings to 9.

In ref. [5] the production of *single* top squarks via R_p violation in $p\bar{p}$ collisions at the Fermilab Tevatron was studied. The work was motivated by the consideration that, while the R_p and baryon number violating couplings λ''_{1jk} which involve an up (s)quark are severely constrained by the absence of neutron-antineutron oscillations [4,6] and double nucleon decay into kaons [7], the limits on the couplings λ''_{3jk} which involve a top (s)quark are much weaker: the authors of ref. [5] quote a 95% confidence level upper bound $\lambda''_{3jk} < 1$. If the couplings are within two orders of magnitude from this upper limit, it turns out that the rate for the production of a single light stop $\tilde{t}_1$ in $p\bar{p}$ collisions at $\sqrt{S} = 2$ TeV exceeds the rate for stop-antistop pair production, due to the greater phase space available. Thus, R_p violation could be the favorite scenario for the observation of supersymmetric particles at the Tevatron.

The authors of ref. [5] considered a minimal supergravity-inspired scenario, where at the Grand Unified Theory (GUT) scale the common gaugino mass is $m_{1/2} = 150$ GeV, the scalar trilinear coupling is $A_0 = -300$ GeV and the common scalar mass m_0 is varied in a range between 50 and 500 GeV. The ratio of the Higgs vacuum expectation values is chosen to be $\tan\beta = 4$ and the Higgs mass parameter μ, whose absolute value is fixed by electroweak symmetry breaking, is chosen to be positive. The R_p and baryon number violating couplings that involve a top (s)quark were taken to be degenerate, $\lambda''_{312} = \lambda''_{313} = \lambda''_{323} \equiv \lambda''$.

The signal coming from single stop production in $p\bar{p}$ collisions, followed by the R_p-conserving decay $\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^+$, with $\tilde{\chi}_1^+ \rightarrow l + \nu + \tilde{\chi}_1^0$, was considered in ref. [5] together with the Standard Model background. The conclusion was that, for $180 < m_{\tilde{t}_1} < 325$ GeV and $\lambda'' > 0.02 - 0.06$, it should be possible to discover the top squark at run II of the Tevatron, otherwise the limit on the R_p-violating couplings could be lowered to $\lambda'' < 0.01 - 0.03$ at 95% confidence level. Moreover, existing data from run I should allow for a reduction of the limit to $\lambda'' < 0.03 - 0.2$ for $180 < m_{\tilde{t}_1} < 280$ GeV.

We studied [1] the bounds on the R_p-violating (s)top couplings that can be derived from present experimental data, and we pointed out that they are in fact more stringent than the bound $\lambda''_{3jk} < 1$ considered in ref. [5]. In particular, we showed that the limits coming from flavor physics put severe constraints on the possibility of discovering single top squarks via R-parity violation at the Tevatron.

Bounds on the R_p-violating couplings can be derived from K^0–$\bar{K}^0$ mixing [7,8,9]. Flavor-changing neutral currents in SUSY models can arise in a "direct" way, when the flavor violation occurs through flavor violating vertices in the diagrams, or in an "indirect" way, due to the existence of non diagonal sfermion masses in the basis where the fermion masses are diagonal. In minimal supergravity scenarios, where the soft mass matrices at the GUT scale are flavor diagonal, non diagonal squark masses are generated by flavor violating couplings through the Renormalization Group Equations. However, as shown in ref. [9], their contribution to K^0–$\bar{K}^0$ mixing can be neglected.

The diagrams that give the dominant contributions to K^0–$\bar{K}^0$ mixing in the scenario considered by the authors of ref. [5] are shown in fig. 1. The most general $\Delta S = 2$ effective Lagrangian can be written as:

$$\mathcal{L}_{\text{eff}}^{\Delta S=2} = \sum_{i=1}^{5} C_i Q_i + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i \,, \tag{2}$$

where the four-fermion operators Q_i and $\tilde{Q}_i$ are defined as in ref. [10]. The operators relevant to this analysis are $Q_1 = \bar{d}_L^\alpha \gamma_\mu s_L^\alpha \; \bar{d}_L^\beta \gamma^\mu s_L^\beta$ (α, β are color indices), coming from the Standard Model diagram (fig. 1a), $\tilde{Q}_1 = \bar{d}_R^\alpha \gamma_\mu s_R^\alpha \; \bar{d}_R^\beta \gamma^\mu s_R^\beta$, coming from the diagrams with four λ'' couplings (fig. 1b-c), and $Q_4 = \bar{d}_R^\alpha s_L^\alpha \; \bar{d}_L^\beta s_R^\beta$, $Q_5 = \bar{d}_R^\alpha s_L^\beta \; \bar{d}_L^\beta s_R^\alpha$, coming from the diagrams with two CKM and two λ'' couplings (fig. 1d-e). The corresponding coefficients C_i are evaluated at a common scale M_S, where the supersymmetric particles are integrated out. We computed the coefficients that are relevant to the case under consideration: their explicit expressions are given in the Appendix.

The contribution of the effective Lagrangian $\mathcal{L}^{\Delta S=2}$ to the K_S–K_L mass difference Δm_K is related to the matrix element $\langle K^0 | \mathcal{L}_{\text{eff}}^{\Delta S=2} | \bar{K}^0 \rangle$. The coefficients C_i must be evolved from the scale M_S, which is of order of the masses of the supersymmetric particles, down to some hadronic scale μ_h (e.g. 2 GeV) at which the matrix element can be evaluated. Moreover, the long-distance hadronic processes give contributions to the matrix elements $\langle K^0 | Q_i | \bar{K}^0 \rangle$ that cannot be evaluated perturbatively, and are parametrized by "bag factors" B_i (for the explicit definitions see ref. [10]). We have calculated the contribution of the R_p-violating couplings to Δm_K, using the NLO QCD evolution of the coefficients C_i and the lattice calculations for the B_i presented in ref. [10]. Due to the large uncertainties that affect the theoretical evaluation of Δm_K in the Standard Model (see e.g. ref. [11] and references therein), a conservative limit on the R_p-violating couplings can be derived by requiring that the contribution to Δm_K of the diagrams shown in fig. 1b-e is not larger than the experimental value $\Delta m_K^{\text{exp}} = (3.489 \pm 0.009) \times 10^{-15}$ GeV. The resulting upper bounds on λ'', in the minimal supergravity scenario considered by the authors of ref. [5] and for the same choice of parameters, are of order $\lambda'' < 0.015 - 0.020$ for a light stop mass ranging between 180 and 325 GeV. Thus, the discovery of single stop production via R-parity violation at the Tevatron turns out to be unlikely.

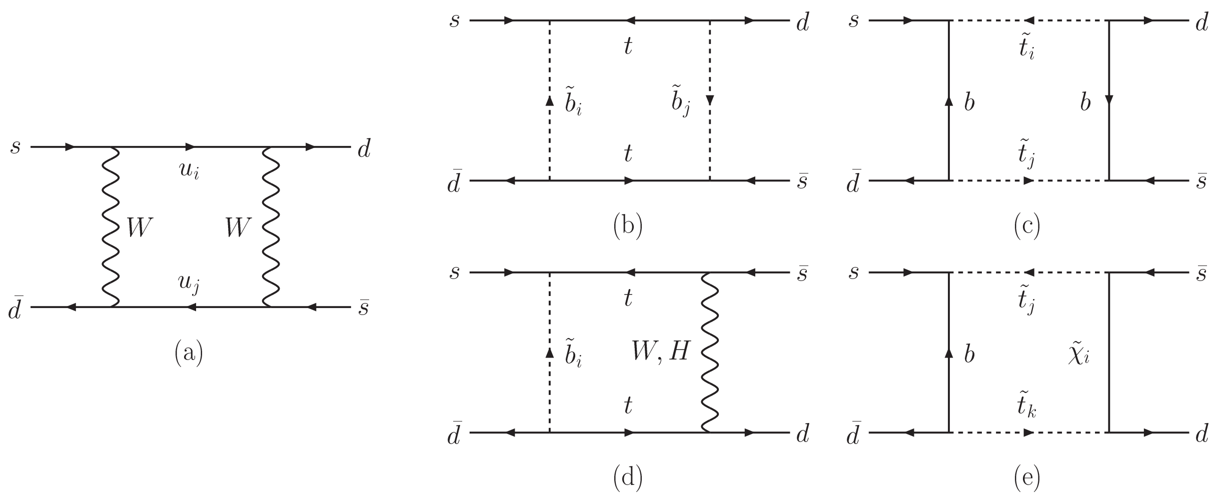

Figure 1: Standard Model diagram (a) and diagrams with $\not{R}_p$-violating couplings (b-e) that give the dominant contributions to K^0–$\bar{K}^0$ mixing. The arrows indicate the flow of baryon number.

There are some other processes that allow to set upper limits on the $\not{R}_p$-violating couplings λ''_{3jk}. The authors of ref. [8] studied the contribution of the $\not{R}_p$-violating terms to the rare decays of the B^+ meson, namely $B^+ \to \bar{K}^0 K^+$ and $B^+ \to \bar{K}^0 \pi^+$. In order to reduce the theoretical uncertainties, they considered the ratio of the partial width of the rare decay to the partial width of the decay $B^+ \to K^+ J/\psi$, which proceeds unsuppressed in the Standard Model. The decay $B^+ \to \bar{K}^0 K^+$ was found to give a more stringent limit on the $\not{R}_p$-violating couplings. Using updated values for the experimental upper bound on the rare decay and for the CKM matrix elements, and taking into account the mixing in the stop sector, we obtain the upper limit $\lambda'' < 0.14 - 0.23$, depending on the light stop mass. This limit is stringent enough to disfavor the possibility that any evidence of single stop production is found in the analysis of the run I data, but it is weaker than the bound derived above from K^0–$\bar{K}^0$ mixing.

In summary, we have improved the existing bounds on the $\not{R}_p$-violating couplings λ''_{3jk}, showing that they are more stringent than those assumed in ref. [5]. From the study of K^0–$\bar{K}^0$ mixing we can set the upper limit $\lambda'' < 0.015 - 0.020$ for the minimal supergravity scenario considered in ref. [5]. As a result, the possibility of detecting single top squark production via R-parity violation at the Tevatron turns out to be strongly limited.

As a final remark, we notice that flavor-changing processes allow to set limits only on products of two different λ''_{3jk} couplings. For example, the bound from K^0–$\bar{K}^0$ mixing concerns in general the combination $|\lambda''_{313}\lambda''^{*}_{323}|^{1/2}$. Thus, the bounds presented in this work could be evaded if only one of the couplings is different from zero, or if there is a strong hierarchy between the different couplings. However, such a situation would need to be justified in terms of some flavor symmetry to be regarded as natural: this point is currently under investigation [1].

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Appendix

We have calculated the contributions to K^0–$\bar{K}^0$ mixing coming from the diagrams with $\not{R}_p$-violating (s)top couplings λ''_{3jk}. The calculation has been performed in the basis where the quark masses are diagonal, and all the flavor changing squark mass insertions have been neglected. We have also checked

that in the minimal supergravity scenario considered in ref. [5] the contributions coming from MSSM diagrams with quarks and charged higgs or squarks and charginos are negligible. The coefficients C_i that appear in eq. (2) are:

$$C_1 = \sum_{i,j=1}^{3} \frac{g^4}{128\pi^2} K^*_{i1} K_{i2} K^*_{j1} K_{j2} m^2_{u_i} m^2_{u_j} \left[I_0 + 2\, I_2/m^2_W + I_4/4\, m^4_W\right](m^2_{u_i}, m^2_{u_j}, m^2_W, m^2_W) \tag{3}$$

$$\tilde{C}_1 = \sum_{i,j=1}^{2} \frac{1}{4\pi^2} |\lambda''_{313}\, \lambda''^*_{323}|^2 \left[(O^t_{i2} O^t_{j2})^2\, I_4(m^2_b, m^2_b, m^2_{\tilde{t}_i}, m^2_{\tilde{t}_j}) + (O^b_{i2} O^b_{j2})^2\, I_4(m^2_{\tilde{b}_i}, m^2_{\tilde{b}_j}, m^2_t, m^2_t)\right] \tag{4}$$

$$\begin{aligned} C_5 = & \sum_{i=1}^{2} \frac{g^2}{4\pi^2} \lambda''_{313}\, \lambda''^*_{323}\, (O^b_{i2})^2\, K^*_{31}\, K_{32}\, m^2_t \Big[I_2(m^2_{\tilde{b}_i}, m^2_W, m^2_t, m^2_t) + \\ & \qquad \frac{1}{4\, m^2_W}\, I_4(m^2_{\tilde{b}_i}, m^2_W, m^2_t, m^2_t) + \frac{1}{4\, m^2_W \tan^2\beta}\, I_4(m^2_{\tilde{b}_i}, m^2_{H^+}, m^2_t, m^2_t) \Big] \\ & + \sum_{i,j,k=1}^{2} \frac{g^2}{8\pi^2} \lambda''_{313}\, \lambda''^*_{323}\, O^t_{j2}\, O^t_{k2}\, K^*_{31}\, K_{32} \left[V^*_{i1}\, O^t_{j1} - \frac{m_t}{\sqrt{2}\, m_W \sin\beta}\, V^*_{i2}\, O^t_{j2} \right] \times \\ & \qquad \left[V_{i1}\, O^t_{k1} - \frac{m_t}{\sqrt{2}\, m_W \sin\beta}\, V_{i2}\, O^t_{k2} \right] I_4(m^2_b, m^2_{\tilde{\chi}^+_i}, m^2_{\tilde{t}_j}, m^2_{\tilde{t}_k}) \end{aligned} \tag{5}$$

and $C_4 = -C_5$. In the above equations, K_{ij} are the CKM matrix elements, O^t_{ij} and O^b_{ij} are the left-right mixing matrices of the stop and sbottom sectors, and V_{ij} is the mixing matrix of positive charginos as defined in ref. [12]. The masses of the supersymmetric particles and the mixing angles at the electroweak scale have been calculated with ISAJET [13], and the common scale M_S has been chosen as the geometrical mean of squark and chargino masses. The functions I_n result from integration over the Euclidean momentum $\bar{k}$ of the four particles circulating in the loop:

$$I_n(m^2_1, m^2_2, m^2_3, m^2_4) = \int_0^\infty \frac{\bar{k}^n\, d\bar{k}^2}{(\bar{k}^2 + m^2_1)(\bar{k}^2 + m^2_2)(\bar{k}^2 + m^2_3)(\bar{k}^2 + m^2_4)} \tag{6}$$

References

1. P. Slavich, in preparation.
2. G. R. Farrar and P. Fayet, Phys. Lett. B 76 (1978) 575.
3. H. Dreiner, in *Perspectives on Supersymmetry*, ed. by G. L. Kane, World Scientific, Singapore (1998), p. 462-479, preprint hep-ph/9707435.
4. F. Zwirner, Phys. Lett. B 132 (1983) 103.
5. E. L. Berger, B. W. Harris and Z. Sullivan, Phys. Rev. Lett. 83 (1999) 4472. Also in B. Allanach *et al.*, *Proceedings of the Workshop on Physics at Run II - Supersymmetry/Higgs*, Fermilab (1998), preprint hep-ph/9906224.
6. J. L. Goity and M. Sher, Phys. Lett. B 346 (1995) 69; erratum *ibid.* B 385 (1996) 500.
7. R. Barbieri and A. Masiero, Nucl. Phys. B 267 (1986) 679.
8. C. E. Carlson, P. Roy and M. Sher, Phys. Lett. B 357 (1995) 99.
9. B. de Carlos and P. L. White, Phys. Rev. D 55 (1997) 4222.
10. M. Ciuchini *et al.*, JHEP 10 (1998) 008, preprint hep-ph/9808328 v2.
11. S. Herrlich and U. Nierste, Nucl. Phys. B 419 (1994) 292, Phys. Rev. D 52 (1995) 6505, Nucl. Phys. B 476 (1996) 27.
12. H. E. Haber and G. L. Kane, Phys. Rept. 117 (1985) 75.
13. H. Baer *et al.*, in *Proceedings of the Workshop on Physics at Current Accelerators and Supercolliders*, ed. by J. Hewett *et al.*, Argonne National Laboratory (1993), preprint hep-ph/9804321.